Development of Improved Back Reflectors for Amorphous Silicon-Based Multi-Junction Technologies

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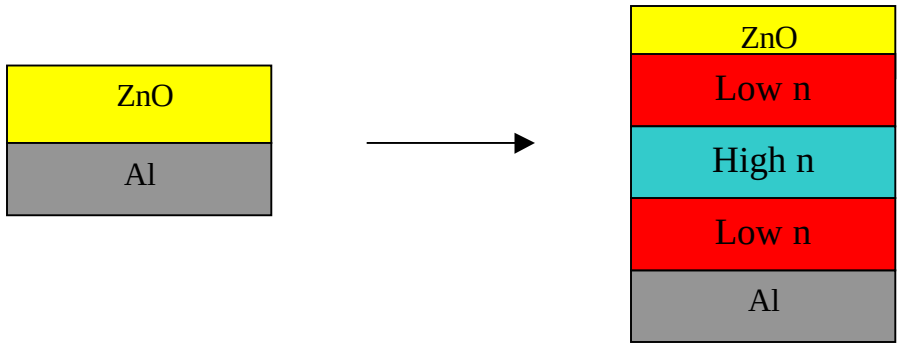
Back Reflector Studies at ECD

Ultimate goal: **Achieve currents obtainable with Ag/ZnO using new back reflector structure that is applicable for long lifetime modules**

First Approach: Take present Al/ZnO back reflector used in production and add optical stack of materials with different indices for refraction. In particular, add layers with contrasting n to enhance reflection in the >600nm region.
Focusing on multi-layer structure of (low n)/(high n)/(low n) materials.



Development of New Al/ZnO Back Reflector

- Have been focusing on Al/Multi-layer/ZnO structure in which multi-layer is ZnOSi/Si/ZnOSi structure.

- Have demonstrated that for back reflectors without textured surfaces a significant improvement in cell performance was obtained using the multi-layer structure.

IV data for a-SiGe cells made with **specular** back reflectors. IV data taken using 630nm filter.

Back Reflector	Voc (V)	Jsc (mA/cm^2)	FF	Rs (ohm cm^2)	Pmax (mW/cm^2)
Al/ZnO	0.564	7.05	0.563	17.8	2.24
Al/ML/ZnO	0.576	8.75	0.558	15.6	2.81

- In contrast, when texture is added by thickening the top ZnO surface, we have yet to see an improvement

IV data for a-SiGe cells with **textured** back reflectors. IV data taken using 630nm filter.

Back Reflector	Voc (V)	Jsc (mA/cm^2)	FF	Rs ($\Omega\ cm^2$)	Pmax (mW/cm^2)
Al/ZnO	0.593	10.4	0.576	12.6	3.55
Al/ML/ZnO	0.605	10.4	0.585	12.5	3.66

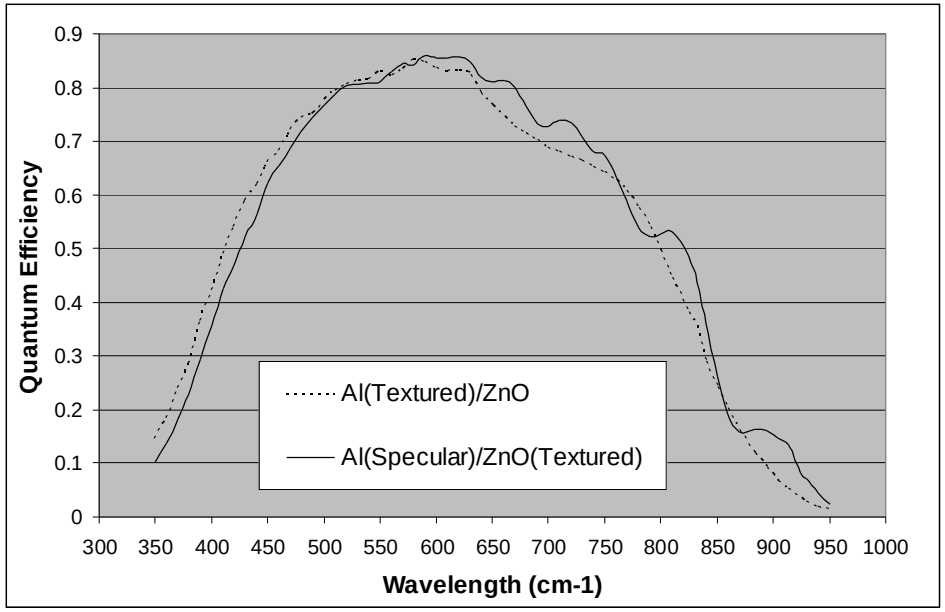
We used Al/ZnO to explore a variety of ZnO deposition conditions to alter the texture of the back reflector.

In doing so, we have found conditions which lead to cells with significantly higher efficiencies than those obtained using United Solar Ovonic's production machine

IV data for a-SiGe cells with **textured** back reflectors. IV data taken using 630nm filter.

Back Reflector	Back Reflector Deposition Machine	Voc (V)	Jsc (mA/cm^2)	FF	Rs ($\Omega\,cm^2$)	Pmax (mW/cm^2)
Al(Textured)/ZnO	Production	0.554	10.30	0.568	12.6	3.25
Al(Textured)/ZnO	R&D	0.587	9.30	0.531	17.4	2.90
Ag/ZnO	R&D	0.575	11.94	0.576	11.2	3.94
Al(specular)/ ZnO(textured)	R&D	0.584	10.81	0.614	10.3	3.88

Quantum Efficiency Plots for A-SiGe:H cells with different back reflectors.

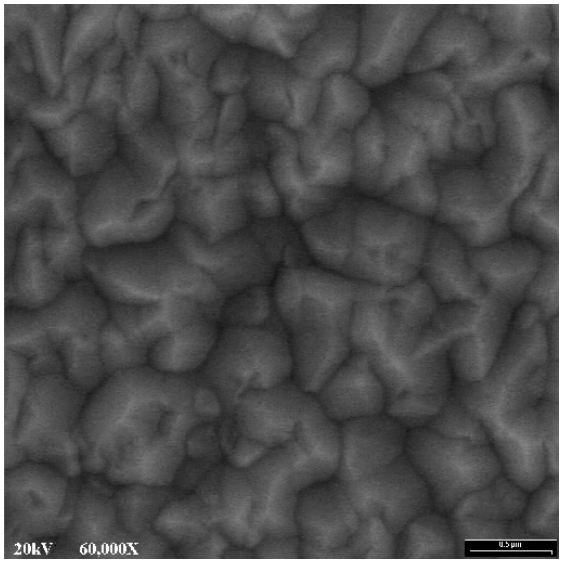


Data for **triple-junction cells** with different back reflectors

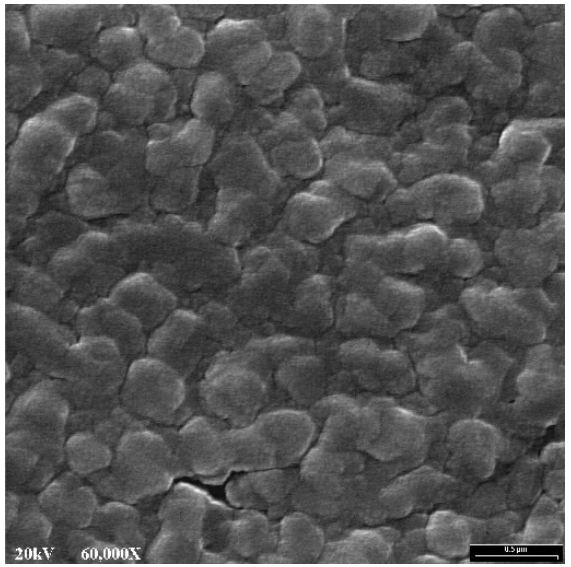
Run #	Back Reflector	Back Reflector Deposition Machine	Pmax (mW/cm^2)	QE Top Cell	QE Middle Cell	QE Bottom Cell	QE Mid+ Bottom Cells	QE Total
3D-2395	Al(textured)/ ZnO	Production	**10.29**	7.09	7.86	7.51	**15.37**	22.46
3D-2395	Al(specular)/ ZnO(textured)	R&D	**10.85**	7.24	8.26	8.75	**17.01**	24.25
3D-2395	Ag/ZnO	R&D	**11.23**	7.31	8.27	9.16	**17.44**	24.74
3D-2403	Al(textured)/ ZnO	Production	**10.09**	7.13	7.37	7.46	**14.83**	21.96
3D-2403	Al(specular)/ ZnO(textured)	R&D	**10.93**	7.30	7.99	8.32	**16.31**	23.61

The Quantum Efficiency values from Middle+Bottom Cells are significantly higher for the Al(specular)/ZnO(textured) as compared with Al(textured)/ZnO demonstrating the improved back reflector performance.

SEM photographs of back reflectors

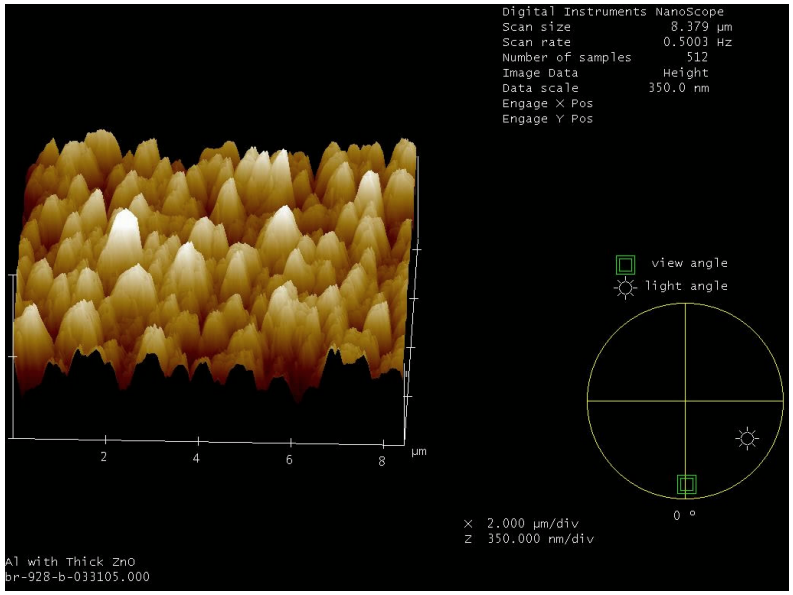


Al(specular)/ZnO(textured)

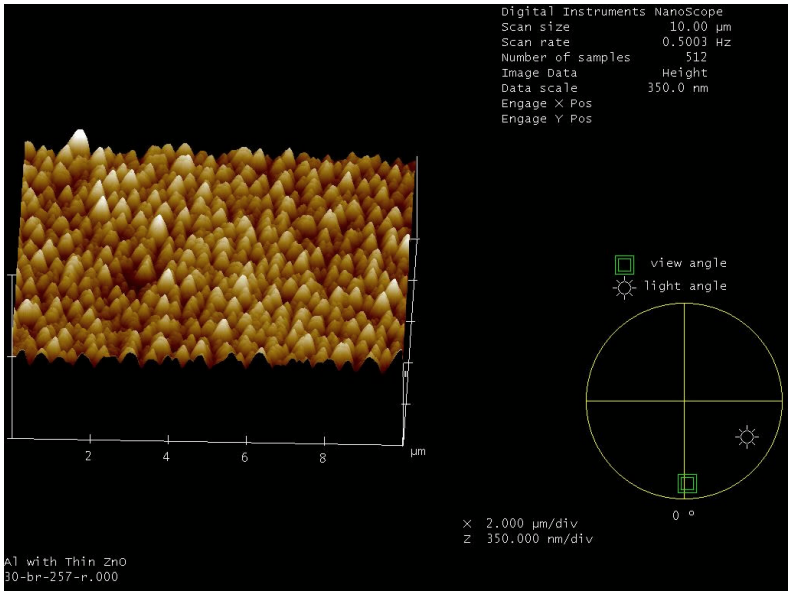


Production Al(textured)/ZnO

AFM photographs of back reflectors

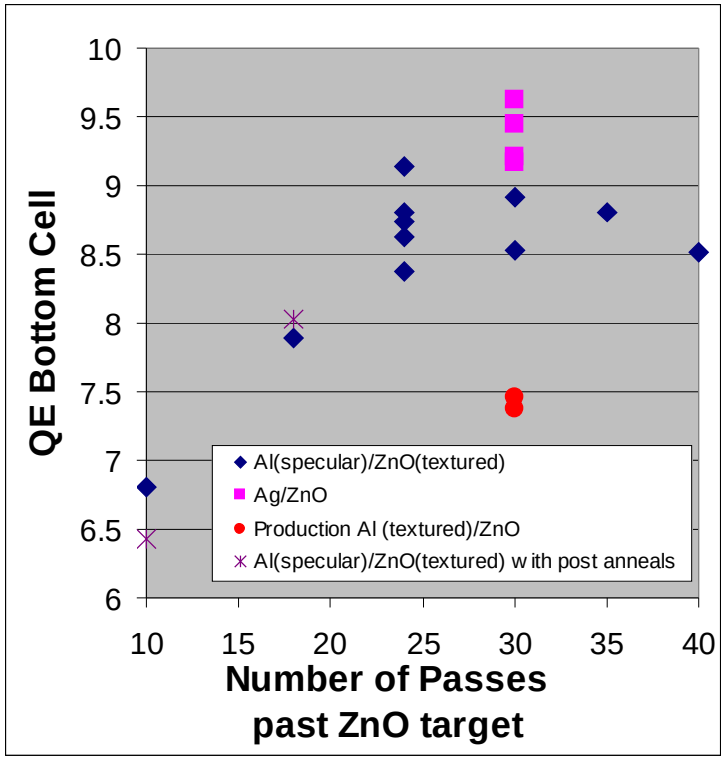


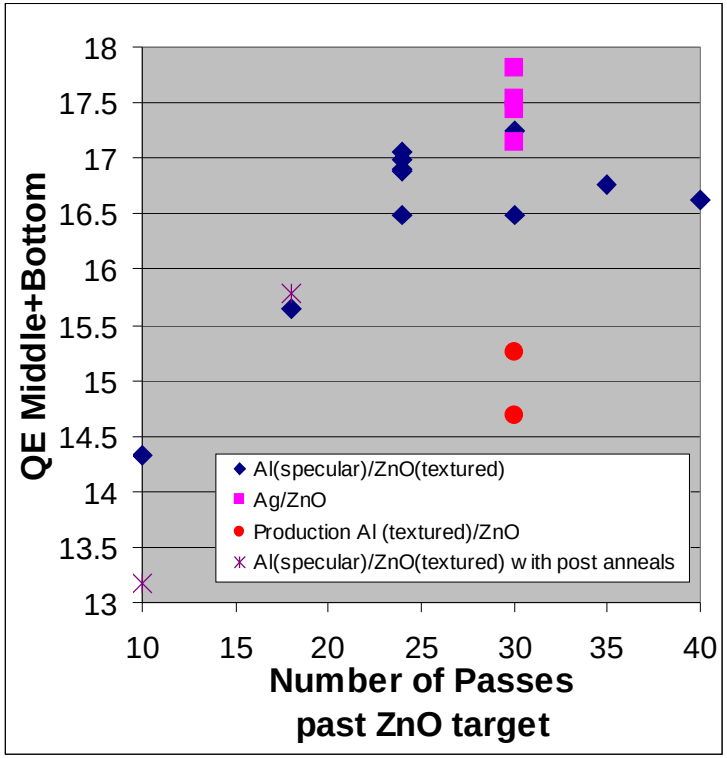
Al(specular)/ZnO(textured)



Production Al(textured)/ZnO

The dependence of QE values for bottom and triple-junction cells made with Al(specular)/ZnO(textured) back reflectors on the number of substrate passes across the ZnO target (and thus the ZnO thickness).





Use of different applied sputtering powers/different deposition rates

IV data for a-SiGe cells with Al(specular)/ZnO(textured) back reflectors.
IV data taken using 630nm filter.

Applied Power (relative)	Voc (V)	**Jsc (mA/cm^2)**	FF	Rs ($\Omega\ cm^2$)	**Pmax (mW/cm^2)**
0.5	0.590	**11.2**	0.592	11.5	**3.92**
1 (STD)	0.599	**10.6**	0.613	10.7	**3.91**
2	0.581	**9.60**	0.609	12.4	**3.39**

Use of ceramic ZnO targets vs. ZnAl metal targets

Can achieve similar results using ZnAl targets however working on reproducibility

IV data for a-SiGe cells with Al(specular)/ZnO(textured) back reflectors.
IV data taken using 630nm filter.

Sputtering Target	Voc (V)	**Jsc (mA/cm^2)**	FF	Rs ($\Omega\ cm^2$)	**Pmax (mW/cm^2)**
ZnO	0.599	**10.6**	0.613	10.7	**3.91**
ZnAl (Avg of 9 samples)	0.575	**11.1**	0.610	9.7	**3.89**

We plan to further develop this new back reflector fabrication process by:

- making further attempts to increase the ZnO deposition rate without a loss in cell efficiency,
- improving the reproducibility when ZnAl targets are used,
- continuing work on Al/Multi-layer/ZnO back reflectors
- attempting to reproduce the results observed in the R&D machines in a large area roll-to-roll line,

Comparison of BR from 5BR, 30BR and R&D

Machine	BR exp	BR type	Voc (V)	**Jsc (mA/cm^2)**	FF	Rs ($\Omega\ cm^2$)	**Pmax (mW/cm^2)**
5BR (Roll-to-Roll)	dd-60	Al/ZnO (thick)	0.560	**10.29**	0.630	8.9	**3.65**
5BR (Roll-to-Roll)	dc-50	Al/ZnO (thick)	0.578	**9.97**	0.646	8.9	**3.72**
TA2 (R&D)	1078C 1086F	Al/ZnO (thick)	0.560	**10.78**	0.600	11.8	**3.64**
30BR (Roll-to-Roll)	257R	Al/ZnO (thin)	0.563	**10.35**	0.557	12.4	**3.25**